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TITLE RADIAL-PULSATION PROPERTIES OF NEUTRON-STAR MODELS

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RADIAL PULSATION PROPERTIES OF NEUTRON STAR MODELS

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ABSTRACT

Preliminary results of a study of the linear, nonadiabatic, radial pulsation properties of neutron star models are presented. Sequences of pure iron models with masses of $1.0 M_{\odot}$ and $1.8 M_{\odot}$ and a range of luminosities and effective temperatures are considered. Magnetic fields are ignored. The densities of the envelopes at their lower boundary range up to $\rho \sim 10^{12}$ g/cm³. Equation of state and opacity tables are modifications of those provided by the Los Alamos opacity library (Huebner, et al., 1977). The motivation for this study was to determine whether or not variations of the iron opacity in the outer layers might produce pulsational instability.

THE MODELS

We have constructed models of the outer layers of pure iron stars with masses of $1.0 M_{\odot}$ and $1.8 M_{\odot}$ and with radii fixed at 1×10^4 m. This is to be compared with observational masses of about $1.4 M_{\odot}$. The luminosities have values of $0.016 \leq L/L_{\odot} \leq 15.0$ and with effective temperatures of 5×10^5 K $\leq T_{\text{eff}} \leq 3 \times 10^6$ K. The position of the inner boundary of the envelope depends on the mass of the envelope (typically 10^{-5} of the mass of the star), but in general is a few hundred meters. Since we are concerned with a very thin layer near the surface we have used the Newtonian equations. The justification for this has been discussed by a number of people (see e.g., Gudmundsson, et al., 1981). The temperature and density near the bottom of the envelope varied from 1.0×10^8 K $\leq T \leq 1.5 \times 10^9$ K and 3.0×10^{11} g/cm³ $\leq \rho \leq 2.0 \times 10^{12}$ g/cm³. The gray approximation is assumed in determining the temperature at the outer boundary while the pressure is given by the approximation suggested by Castor and reported by Stellingwerf (1975). The density corresponding to this temperature is of the order of 2×10^{-2} g/cm³.

Los Alamos opacities are used for the lower densities with conduction due to the degenerate electrons taken from Sweigert's (1973) fit to the Hubbard and Lampe (1969) tables. The equation of state for the lower densities is from the Los Alamos tables with the appropriate degenerate, partially relativistic relations being used at the higher densities (see e.g., Cox and Giuli, 1968). Figure 1 is a plot of the Rosseland mean opacity (excluding conduction) as a function of temperature for densities in the

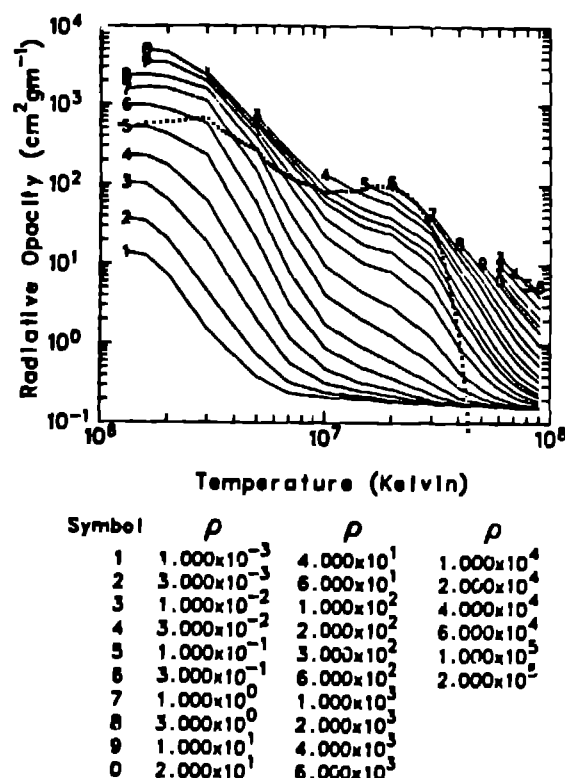


Fig. 1. The radiative opacities are plotted for pure iron. The actual table includes both lower and higher temperatures. They have been eliminated here for plotting purposes. Each curve corresponds to a different density. The dotted curve represents the structure of a model, including conduction, with effective temperature near 1×10^6 K.

range of interest. The structure of a typical model with T_{eff} near 10^6 K is shown. The model of course included conduction and therefore at high temperatures the effective opacity becomes very small and the temperature nearly constant. The bumps in the opacity near $T \approx 2 \times 10^7$ K and $T \approx 2 \times 10^6$ K are due to K and L shell ionization. It is these features that might be expected to provide some destabilization of the envelope.

A criterion for destabilization due to an envelope ionization mechanism has been discussed by Cox and Ciuli (1968). If the quantity

$$\phi(m) = \frac{1}{L(\Pi/2\pi)} \int_m^M C_v T dm \approx 1.0 \quad ,$$

then the destabilizing region is at the correct depth to be maximally effective in driving the pulsations. In the above relation L is the stellar luminosity, Π the period of pulsation, M the stellar mass and m the mass interior at the point in question. C_v and T have their usual thermodynamic meanings. $\phi(m)$ is approximately the ratio, for the equilibrium model, of

the internal energy above the level having interior mass m , to the energy radiated in $1/2\pi$ pulsation periods.

For our hottest models, this is at a $T \approx 22 \times 10^6$ K and near the peak of the opacity bump which occurs at $T \approx 20 \times 10^6$ K. Our coolest model has $\phi \approx 1.0$ at $T \approx 3.4 \times 10^6$ K whereas a small opacity bump occurs at $T \approx 2.0 \times 10^6$ K. At this time we have, for technical reasons, been unable to obtain models with effective temperatures less than approximately 5×10^5 K.

The PdV work per zone for our hottest model is shown in Figure 2 for the fundamental mode. This mode is stable with a fractional kinetic energy growth (decay) rate per period of $\eta_0 \approx -9 \times 10^{-15}$. All other modes investigated (through the eighth overtone) are more stable than the fundamental. The models are highly adiabatic with the very small growth rates being quite sensitive to details of the opacity and equation of state data. The small positive peak near zone 145 is related to the aforementioned K-shell ionization. The large excursions near zones 120 (negative) and 125 (positive) are due to discontinuities in $d\ln\kappa/d\ln\rho$ and are evidently caused by the coarseness of the tables. The temperature and density of this region are $T \approx 70\text{--}80 \times 10^6$ K and $\rho \approx 1 \times 10^4$ g/cm³. A work plot for a

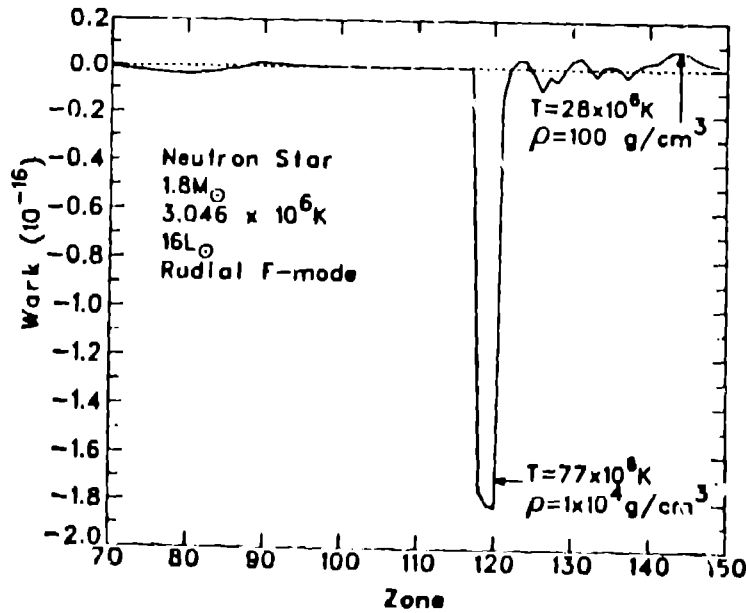


Fig. 2. PdV work as a function of zone number for a model with effective temperature near 3×10^6 K. Temperature and density are indicated at two different points. As indicated in the text, most of the structure is spurious.

lower temperature ($T_{\text{eff}} \approx 1 \times 10^6$ K) shows more structure but again it is mostly spurious. We have not found any models that show a believable positive growth rate.

The fundamental eigenfunction is large throughout the extent of our envelope and therefore since the inner boundary is held fixed the period is not well determined. We have looked at some models which went considerably deeper to see the effect on the calculated periods. The fundamental period of the deepest model constructed was $\Pi_0 \approx 1 \times 10^{-4}$ s with the pulsation constant $Q_0 \approx 0.03$ days. Since these deep models reach densities much too high for our equation-of-state data to be valid we do not discuss them further.

CONCLUSIONS

The opacity mechanism does produce some driving in the outer layers of pure iron neutron stars. It is, however, not sufficient to overcome the damping for any of the models that we have investigated. The calculations are fairly sensitive to the exact details of the opacity tables. Due to the highly adiabatic character of the pulsations small differences in opacity derivatives can produce spurious amounts of driving or damping.

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